Visual fields: back to the future.

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Visual Fields: Back to the Future

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Introduction

The past few decades have seen glaucoma research undergo significant advances, particularly in the areas of pathophysiology and investigative techniques. While new sophisticated methods of imaging the retina and optic nerve and measuring intraocular pressure have become available of late, many clinicians still find themselves using the same tests for measuring the visual field that have been used in previous generations. What real advancements have been made in recent years and where is perimetry going?

A brief history

Perimetry is the quantitative evaluation of the visual field and has been a subject of interest to philosophers, scientists and clinicians for over 2500 years. Although the visual field was being measured by various scientists, such as da Vinci, Young and Purkinje, the introduction of visual field testing in medical practice is attributed to Von Graefe. Von Graefe used a flat wire grid, similar to that previously used by Helmholtz to direct a patient's fixation during fundoscopy, in order to map scotomata in his patients. Scientists soon began to recognise the importance of maintaining a constant distance between the test object and the eye, and so arc perimetry was introduced. In 1889, Bjerrum introduced a method for examining for defects in the central visual field in a short note entitled *An addendum to the usual examination of the visual field of glaucoma*, and first described his finding of an arcuate scotoma at approximately 15° retinal eccentricity in people with glaucoma. This technique involved the movement of circular discs of different sizes (attached to a wand) from the periphery to the centre of a black cloth screen (ie from areas of non-seeing to seeing) – a perimeter now commonly known as a Bjerrum tangent screen.

Goldmann introduced his eponymous bowl perimeter in 1945, which employed much the same principle, with the added benefits of better defect quantification and a shorter working distance than the Bjerrum screen, allowing a greater extent of the field to be measured. Goldmann standardised test conditions such as background luminance and stimulus luminance and introduced the popular Goldmann stimulus sizes (0–V).

In 1959, Harms & Aulhorn employed static stimuli on a bowl perimeter (the Tübingen perimeter), allowing more precise quantification of the sensitivity of the visual field at precise locations and hence more accurate grading and monitoring of disease. This was the forerunner of standard static automated perimetry (SAP) that is used in many ophthalmic clinics worldwide today. Threshold-related screening techniques were developed and evaluated alongside thresholding techniques as methods of rapid and efficient disease detection (Drance et al. 1972; Harrington & Flocks 1954). The 1980s saw the evolution of automated perimetry as well as various methods incorporating novel types of stimulus, following ever-updated reports on glaucomatous pathophysiology and proposals of selective loss of specific cell types. Today, many different screening and thresholding techniques exist.

Why measure the visual field?

Measurement of the visual field is of great importance in the investigation of many conditions affecting the visual pathway, including retinal lesions, compressive lesions and vascular accidents. It is also well understood that, for evaluation of some conditions, the extent of the visual field is of most importance, while for other conditions, the depth of the defect is equally as important. Perhaps the most common reasons for performing perimetry are the detection, evaluation and monitoring of glaucoma. Visual field defects in glaucoma can influence hand–eye coordination (Kotecha et al. 2009), increase the probability of falling (Haymes et al. 2007) and, perhaps crucially, increase the risk of causing or being involved in a motor vehicle accident (Haymes et al. 2007; McGwin et al. 2005). As such, knowledge of the extent and depth of visual disability in the presence of glaucoma, and any progression thereof, is essential. Although many of the basic principles, methods, standards and much of the instrumentation employed in perimetry have remained largely unchanged over the past few decades, significant progress in perimetric research of late has led to improved accuracy and precision in glaucoma diagnosis and monitoring. However, new innovations, including those in perimetric research, are often slow to reach the ophthalmic clinic and the optometrists' practice. One study has revealed that it takes 17 years (on average) for research findings to be translated from a laboratory setting to a clinical setting (Balas & Boren 2000).

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This article will discuss recent attempts to identify more precisely the mechanisms by which the visual system responds to conventional perimetric stimuli, with a view to improving the diagnostic accuracy and clinical meaning of results from SAP. A comprehensive indepth report of all recent research findings is beyond the scope of the current article; however previously published reports will be indicated where appropriate.

Perimetry in glaucoma – where are we now?

Glaucoma is characterised by a loss of retinal ganglion cells (Quigley et al. 1982) and this loss can be detected clinically by measuring either retinal structure or visual function.

Visual field testing remains the primary functional biomarker for the presence of glaucoma and its progression. The ideal perimetric test for glaucoma is one that is highly sensitive and specific to the condition, reproducible, quick and patient-friendly. Currently, no perimetric test exists that meets all of these criteria simultaneously. It is often reported by clinicians and researchers that significant ganglion cell loss (up to 50%) can occur before SAP can adequately detect functional loss. These notions come from the findings of studies such as those of Quigley et al. (1982) and Harwerth et al. (1999). However, the former study suffered considerably from a low sample size, and the latter from the log-linear scale used to present the data graphically, ie when a log value (sensitivity loss in decibels) was plotted against a linear value, larger, later losses of ganglion cells were emphasised, and smaller, earlier losses less so (Figure 1).

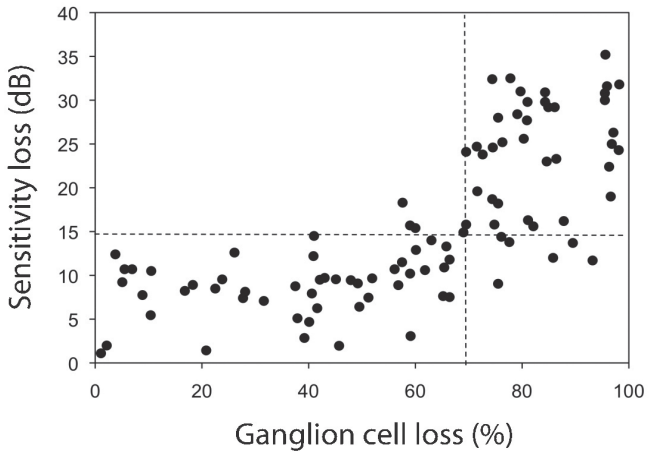

Figure 1. The relationship between sensitivity loss and ganglion cell loss in the macaque eye. Adapted from Harwerth et al. (1999).

A later paper by Garway-Heath et al. (2002), employing temporal rim area, measured with a Heidelberg retina tomograph (HRT: Heidelberg Engineering, Heidelberg, Germany), as the structural measure showed that, when structure and function are both plotted on a common scale, the association between them becomes linear. One striking feature of the data of Garway-Heath et al. (2002) is that, although structure and function can be linearly associated when plotted on a common scale, considerable variability exists (Figure 2). Swanson et al. (2004) and Pan & Swanson (2006) provided even more food for thought. Importantly, they point out that one obvious and very notable oversight in the relationship between retinal structure and visual function is the influence of higher-level cortical processing on the perimetric stimulus. The majority of published clinical research on the structure/function relationship in glaucoma has concentrated on the relationship between visual field sensitivity and retinal structure (Garway-Heath et al. 2002; Harwerth et al. 1999; Hood & Kardon 2007; Quigley et al. 1982). Although these studies provide reasonable suggestions for sources of discrepancy between these parameters, the effect of higher-level cortical processing has received disproportionately little attention. It is convenient to assume that the rate of visual field loss is equal to the rate of retinal ganglion cell loss in glaucoma. However, consideration of the many levels of stimulus processing higher up in the visual system (eg in the visual cortex), as well as the scale on which measurements are plotted, may render such an assumption simplistic. Swanson et al. (2004) proposed a two-stage relationship between perimetric sensitivity (measured with a Humphrey field analyzer) and underlying ganglion cell density in the healthy eye, accounting both for differences in ganglion cell density at different retinal eccentricities as well as differences in cortical processing for those eccentricities.

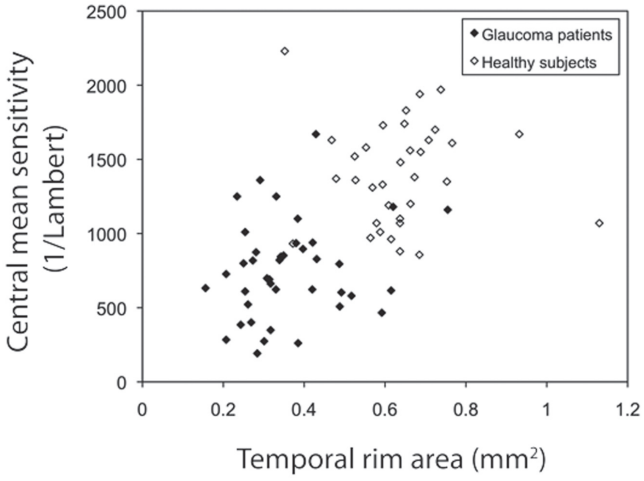

Figure 2. The structure/function relationship is linear when data are plotted on linear axes. Adapted from Garway-Heath et al. (2002).

While the structure/function relationship has interested scientists and clinicians for many years, consideration of higher-level processing depends on whether one wishes to know the relationship between ganglion cell loss and the resulting drop in visual field sensitivity, or how results of a functional test relate to those of a structural test in a between-test comparison. Reports of significant retinal ganglion cell loss prior to detection of glaucoma by conventional static perimetry, along with reports of high measurement variability (Artes et al. 2005; Wall et al. 2009), particularly in regions of reduced sensitivity, have gained

widespread attention and have subsequently catalysed the development of more objective tests for measuring structures such as optic disc neuroretinal rim area, eg HRT, and retinal nerve fibre thickness, eg GDx (Carl Zeiss Meditec, Dublin, CA) or optical coherence tomography (OCT). While imaging technology such as OCT has certainly made a valuable contribution to the detection of disease and its progression in optometric practice, it must be borne in mind that such objective tests merely allow surrogate measures of ganglion cell axon density and, perhaps more importantly, do not measure what we are ultimately trying to preserve, namely ganglion cell function. For similar reasons as those described above, various alternative forms of perimetry have been investigated, such as frequency-doubling technology (FDT) (Johnson & Samuels 1997), short-wavelength automated perimetry (SWAP) (Johnson et al. 1993; Sample & Weinreb 1990), high-pass resolution perimetry (Frisen 1987) and motion perimetry (Verdon-Roe et al. 2006; Wall et al. 2009). While a large body of research continues to focus on such alternative perimetric methods for characterising visual sensitivity, other significant areas of perimetric research include the investigation of ways in which noise, from either measurement or analysis, can be overcome, in order to improve the disease 'signal', ie improve the ability of tests to report the definite presence or progression of glaucoma (Artes & Chauhan 2009; Chauhan et al. 2008; Turpin et al. 2007). In addition, methods for improving clinical interpretation of results of existing test modalities (Bengtsson et al. 2009; Viswanathan et al. 1997) and screening methods such as suprathreshold perimetry (Artes et al. 2003; Henson & Artes 2002) have been developed. Recent interest has also been directed towards the appropriate frequency of visual field testing to detect progression (Crabb & Garway-Heath 2009; Heijl et al. 2008) and the ways in which existing test stimuli can be altered in order to make results more repeatable (Redmond et al. 2010; Wall et al. 2009).

To date, prediction of visual field defects from structural measures remains poor (Zhu et al. 2010) and we are not currently in a position to replace measurements of visual function with measurements of retinal structure or vice versa. It is widely accepted by clinicians and scientists alike that consideration of results from functional and structural tests in combination affords greater power to clinical decision-making.

Why are we still using standard automated perimetry?

It is reasonable to ask why the visual field is measured using scenes that do not mimic real-world tasks. Currently, the gold-standard method for measuring the visual field is to record the ability to detect small, brief, white circular stimuli on a white background. This is hardly a visual task that is performed during a normal everyday schedule. It may therefore be argued that tests of visual function that are more representative of real-world tasks (eg the presentation of stimuli on natural images) should instead be used to measure simultaneously the impact of glaucoma on everyday seeing and quality of life. Additionally, some may argue that current methods of measuring the visual field are rudimentary and outdated. While this might appear to be the case, it can also be argued that the test has the advantage of being a widely understood perimetric test. Almost all of our understanding of visual field progression in glaucoma comes from clinical trials and other studies that have used only standard automated perimetry to define the visual field. Furthermore, the test is a stable technology, very familiar to clinicians in most hospital glaucoma clinics and optometric practices, and many clinicians may have reservations about switching from one perimeter to another while in the process of carefully monitoring a patient for the presence of glaucoma or its progression. It is reasonable to propose that, for effective monitoring of glaucoma, frequent, stable tests are required, regardless of whether they are new or old. Despite many years of developing newer perimetric tests, as well as clinical structural tests, SAP has stubbornly remained the gold standard for the detection and monitoring of glaucoma and, as such, it is important that one understands fully the results that it reports, even though these results are often subject to considerable variability.

It might reasonably be argued that the better use of existing perimetric tests (including appropriate frequency of testing) and better analysis of their results can build on our clinical understanding of the way in which patients are affected visually in glaucoma, as well as help us identify glaucoma in its earliest stages or the smallest signs of progression. To do this, it is worth considering the fundamentals of detection of a spot stimulus and how the ability of the visual system to process the stimulus changes as the disease progresses. Currently, SAP can be performed using a range of stimulus sizes (Goldmann sizes), while the duration of the stimulus on the screen is generally fixed at 0.2 seconds. Stimuli are varied in brightness according to the response of the patient, until threshold contrast is reached. This is translated into a clinically meaningful visual field sensitivity value. Fundamentally, in SAP, one is measuring the lowest number of photons eliciting a response in the visual pathway for a fixed stimulus size. However, the number of photons delivered to the retina can be altered in various ways. For example, instead of increasing the number of photons by increasing stimulus contrast, one could increase the area of the stimulus, while keeping the contrast constant. Likewise, one could fix the area and contrast of the stimulus and increase its duration. As a consequence, three potential variables warrant consideration: stimulus contrast, area and duration. Varying contrast, area and duration (either in isolation or simultaneously) may well have different degrees of success in the detection and monitoring of glaucoma. Anderson (2006) reminded us that Goldmann stimuli were introduced to SAP from kinetic bowl perimetry, as were the stimulus duration of 0.2 seconds and the background luminance of 10cd/m^2, and that as long as there is standardisation of methods in SAP, it is not essential that these parameters are fixed at the levels recommended for kinetic perimetry. Careful consideration of the way in which these parameters should be altered suggests that a considerable amount of the variability and reduced diagnostic accuracy of conventional SAP may be explained by the inappropriate importation of fixed parameters from a different perimetry type.

Spatial summation: basic principles and relevance to perimetry

'Summation' is the term given to the way in which the visual system adds up the light energy within a stimulus. 'Spatial summation' is the ability of the visual system to add up light energy across a given stimulus area. It is a phenomenon that was investigated at great length by scientists in the latter half of the 19th century and throughout the 20th century and is highly relevant to perimetry. Only in the past 20 years or so has interest in spatial summation made a revival in perimetric literature. The retina absorbs the photon light energy that reaches it from a visual stimulus. Threshold is reached when the stimulus contains enough energy overall to overcome visual noise and elicit a visual response. For a range of small stimuli the effect of changing either size or intensity is proportionally the same, such that reducing the intensity of a stimulus at threshold by 50% means that the stimulus must be twice as large in order to reach threshold again, ie stimulus area (*A*) and stimulus intensity (*I*) are inversely proportional: $I \times A = k$, and the slope of the line joining threshold values for these stimuli is –1 (Figure 3). This relationship is commonly referred to as Ricco's law and describes complete spatial summation. However, this relationship breaks down for larger stimuli and summation is said to be incomplete, in that a twofold decrease in stimulus intensity is no longer compensated for by a doubling of the stimulus area. On the spatial summation curve (Figure 3), the slope of the line joining thresholds for these larger stimuli is between 0 and –1, depending on testing conditions. At what point does complete summation break down? The largest stimulus size for which complete summation still applies is known as the critical summation area or Ricco's area (the kink in the curve in Figure 3).

The exact physiological basis for this limit to complete spatial summation has been a topic of great debate for many decades, but it has traditionally been thought to represent the size of the centre mechanism of centre/surround receptive fields (Figure 3) of retinal ganglion cells (Glezer 1965). However, more recent studies have suggested that the size of Ricco's area is influenced by the extent of receptive fields of cortical cells (Pan & Swanson 2006; Swanson et al. 2004). Regardless of the exact underlying physiology, measured sensitivity depends on whether the stimulus is small enough to undergo complete summation or if it is sufficiently large that it will undergo incomplete summation. Thus, the way in which perimetric sensitivity levels change in response to ganglion cell loss is determined by whether the stimulus size is larger or smaller than Ricco's area (Anderson 2006). Ricco's area is not a fixed parameter. It is larger in the retinal periphery (Volbrecht et al. 2000; Wilson 1970), larger under lower levels of background luminance (Barlow 1958; Glezer 1965) and larger for stimuli of shorter duration (Hood & Finkelstein 1986). Ricco's area also differs for stimuli of different wavelength (Brindley 1954; Volbrecht et al. 2000) and therefore influences the way in which sensitivity values for standard white-on-white perimetry and short-wavelength perimetry should be compared.

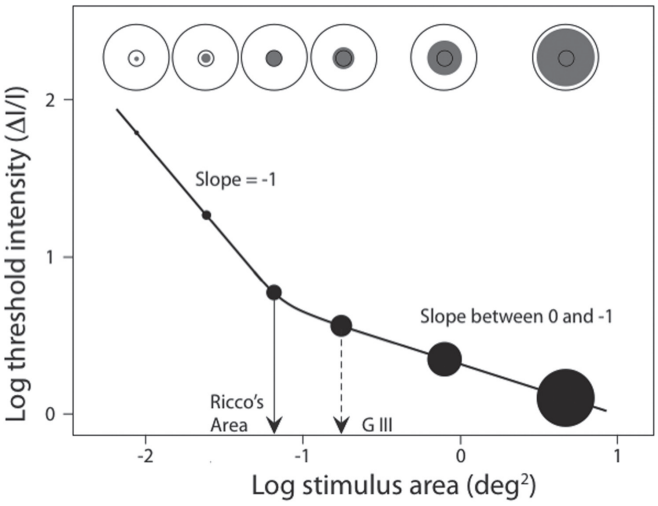

Figure 3. Schematic of a typical white-on-white spatial summation curve. A slope of –1 indicates an inverse relationship between area and intensity at threshold (Ricco's law applies). For stimuli larger than Ricco's area (denoted by solid arrow), this relationship no longer holds. Data points are larger for larger stimuli, to aid interpretation. The size of a Goldmann III stimulus is denoted by the dashed arrow. Centre/surround receptive fields are shown on top, showing the relative size of the stimulus and the receptive field. It is thought that Ricco's area is the stimulus size that equates to the size of a receptive field centre and that Ricco's law breaks down once the stimulus is larger than the receptive field centre.

Considering spatial summation in the context of clinical perimetry, the size of Ricco's area for white stimuli on a white background is very small, although it does enlarge with retinal eccentricity (Wilson 1970). By contrast, the size of the stimulus employed in SAP (the Goldmann III) remains constant. Therefore, one might expect that Ricco's area may be larger or smaller than the Goldmann III stimulus at different regions of the retina. Indeed, Ricco's area is much smaller than the Goldmann III stimulus for most of the central retina. At approximately 15° retinal eccentricity however, Ricco's area is approximately equal in size to a Goldmann III stimulus and is larger than it is at regions beyond 15°. This means that, within 15° in the normal eye, threshold is determined by incomplete spatial summation, whereas beyond 15°, it is determined by complete spatial summation. Interestingly, Wilson (1970) found that, while Ricco's area enlarges with greater eccentricity from the fovea, sensitivity for Ricco's area-sized stimuli remains constant. Put simply, this is evidence for a scaling factor with eccentricity (rather like a cortical magnification factor) that is probably regulated by cortical receptive fields. The relationship between retinal structure and visual function described by Swanson et al. (2004) for the healthy retina takes these findings into account (Figure 4).

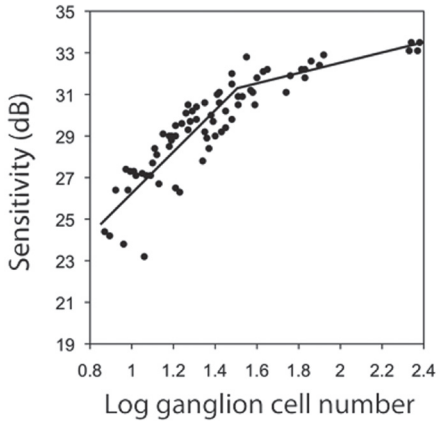

Figure 4. The two-stage structure/function model of Swanson et al. (2004). Adapted from Swanson et al. (2004).

These authors calculated that, beyond 15° retinal eccentricity, where the stimulus is smaller than Ricco's area, sensitivity declines by 1 log unit (ie 10dB) for each log unit reduction in ganglion cell number (dB = 10 × log(x)). However, within 15°, where the stimulus is larger than Ricco's area, sensitivity declines by 0.25 log units (ie 2.5dB) for each log unit decrease in ganglion cell number. So, the relative size of the stimulus and Ricco's area determines the normal sensitivity level for a given ganglion cell density.

Ricco's area in glaucoma

Fellman et al. (1989) carried out a series of experiments investigating spatial summation in glaucoma and made several observations. They found that the difference in threshold between Goldmann III and V stimuli was greater in glaucoma patients than in healthy controls. They also demonstrated that, in attempting to improve visibility of the stimulus, increasing the area of the stimulus had a greater effect in glaucoma patients than increasing contrast. In normals, they found the opposite to be the case. The authors concluded that the increased sensitivity to larger stimuli in glaucoma could be due to either the stimulus covering more normal retinal areas that surround the defective region or pathological spatial summation whereby light is absorbed over a larger area than would be expected in the normal eye. Ricco's area has recently been shown to enlarge in glaucoma (Redmond et al. 2010) (Figure 5). Interestingly, the spatial summation curve undergoes a direct rightward shift in glaucoma, with no vertical shift, and the sensitivity at Ricco's area is the same between patients and healthy controls.

When changes in Ricco's area are accounted for, ie when the glaucoma curve is displaced back along the *x*-axis by an amount equal in size to the change in Ricco's area, sensitivity for glaucoma patients and healthy subjects is equivalent, indicating that changes in Ricco's area can account for most, if not all, of the sensitivity loss found in early glaucoma using conventional Goldmann III stimuli (see Figure 5 in Redmond et al. (2010)). Such a finding suggests an adaptive mechanism in the visual cortex to preserve visual sensitivity in response to ganglion cell loss. If one assumes that Ricco's area is related to receptive fields in the visual cortex, an enlargement of

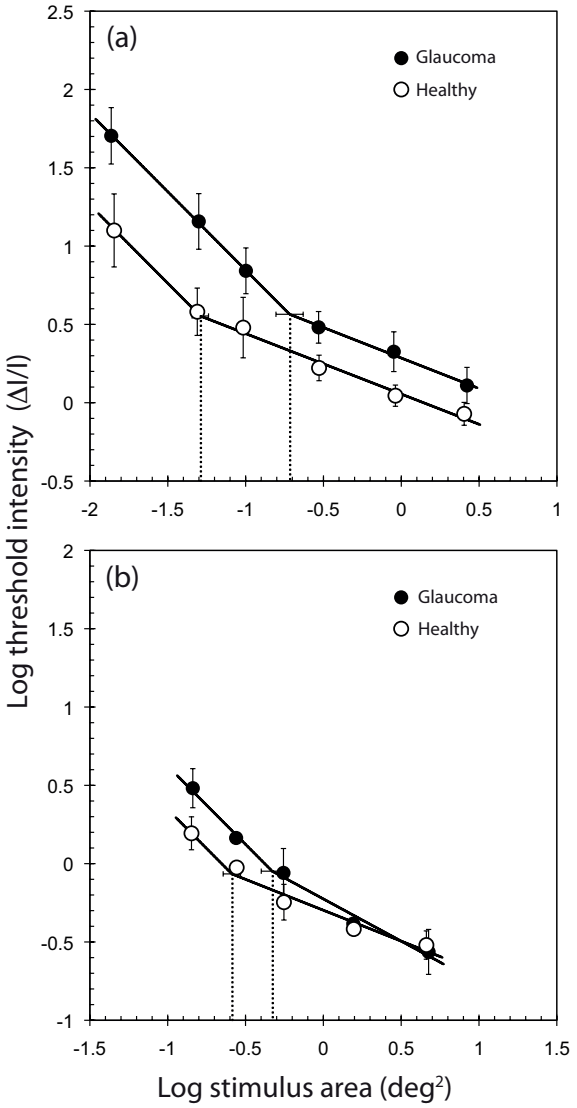

Figure 5. Spatial summation curves for (a) white-on-white stimuli and (b) blue-on-yellow stimuli. Curves are shown for the superior visual field only. Dotted lines indicate the size of Ricco's area in each case. Adapted from Redmond et al. (2010).

Ricco's area suggests that, when ganglion cells die, cortical cells to which the dead ganglion cells once projected receive extra input from remaining ganglion cells adjacent to those that have died, ie greater convergence of ganglion cells on to cortical cells. This finding is similar to that of Wilson (1970), of an enlargement of Ricco's area with eccentricity in the normal eye, and indicates that the structure/function relationship found by Swanson et al. (2004) may also be applied to the glaucomatous eye. Clinically, the finding of an enlarged Ricco's area in glaucoma means that the size of the stimulus employed in perimetry should be compared to the size of Ricco's area for that stage of the disease in order to calculate the rate of sensitivity loss per unit ganglion cell loss. When Ricco's area is smaller than the Goldmann III stimulus, sensitivity should decline at a rate of 2.5dB per log unit decline in ganglion cell density (incomplete summation). When Ricco's area enlarges beyond the size of a Goldmann III stimulus, sensitivity should decline thereafter at a rate of 10dB per log unit decline in ganglion cell density (complete summation). Swanson et al.

(2004) estimated the SAP sensitivity for a stimulus of equal size to Ricco's area to be constant at 31.25dB, regardless of the region of retina being tested. This means that summation switches from incomplete to complete at 31.25dB. In other words, a 1dB reduction in sensitivity above 31.25dB indicates a reduction of ganglion cell density of 0.4 log units whereas a 1dB reduction in sensitivity below 31.25dB suggests a ganglion cell reduction of only 0.1 log units. It is important to note that sensitivity values reported by Swanson et al. (2004) were specific to the Humphrey Field Analyzer I (Carl Zeiss Meditec, Dublin, CA). Researchers and clinicians often consider the rate at which SAP sensitivity declines. It is well known among clinicians that SAP sensitivity is highly variable, with variability increasing as visual loss increases. It is reasonable to suggest that, in the early stages of disease, where the rate of SAP sensitivity loss is shallow compared to the loss of ganglion cells, subtle sensitivity loss, in the presence of high measurement variability, is detected with greater confidence once Ricco's area becomes larger than the stimulus.

Exploiting changes in Ricco's area in glaucoma

How could we use information about the changing nature of Ricco's area in glaucoma to improve clinical testing? Why don't we simply perform SAP with a stimulus that is always smaller than Ricco's area? This suggestion is valid; however it is also known that in SAP, where the varying parameter is contrast, sensitivity measurements are more variable for smaller stimuli than for larger stimuli (Gilpin et al. 1990). Plotting a patient's spatial summation curve would require the patient to undertake multiple visual field tests using differently sized stimuli, and in a busy optometric practice or hospital clinic this is not feasible. Estimating the degree of enlargement of Ricco's area from conventional stimuli varying in contrast is challenging and can often be inaccurate. Anderson (2006) and Redmond et al. (2010) suggest an alternative approach whereby stimulus area is varied either instead of intensity (stimuli varying along the *x*-axis in Figures 3 and 5), or simultaneously with it (stimuli varying diagonally at 45° in Figures 3 and 5) after each patient response. A stimulus varying in area, with a starting value smaller than Ricco's area, would offer the potential to measure directly the lateral displacement of the spatial summation curve in each patient and improve the ability of the test to report definite presence or progression of glaucoma at the same time. Furthermore, this modification to SAP may readily be applied to current instrumentation without changing the task or experience of the patient. If the contrast and size of the stimulus are arranged such that the stimulus always undergoes complete spatial summation (ie if the size of the stimulus is always smaller than Ricco's area), then the rate of sensitivity loss will always be expected to be 1 log unit for every log unit decline in ganglion cell density. The importance of altering stimulus size in perimetry has also been acknowledged in other contemporary works (Johnson et al. 2010; Wall et al. 2009).

Other changing perspectives in perimetry

Recent years have witnessed a revolution of ideas in clinical perimetry. While some newer perimetric tests have been welcomed in clinical practice, other promising tests of visual function in glaucoma have been almost completely abandoned in the clinical setting. SWAP was first introduced in the early 1990s and early investigations into the usefulness of the technique in measuring glaucomatous loss suggested that sensitivity to blue stimuli on a yellow background was reduced before sensitivity loss for conventional white-on-white stimuli could be detected (Johnson et al. 1993; Sample & Weinreb 1990). One study suggested that sensitivity loss in glaucoma could be predicted by SWAP up to 3–5 years before being detected by SAP (Johnson et al. 1993). More recent investigations in this area have revealed that SAP identifies almost as many patients with early glaucoma as SWAP (Bengtsson & Heijl 2006), with one study even reporting that sensitivity loss could be detected by SAP before it could be detected by SWAP (van der Schoot et al. 2009). In consideration of changes in spatial summation in glaucoma, Redmond et al. (2010) found that Ricco's area for blue-on-yellow stimuli also enlarged in glaucoma, but by a lesser amount than that for white-on-white stimuli (Figure 5b). Furthermore, the relative difference in size between Ricco's area for blue-on-yellow stimuli and the Goldmann V stimulus used in SWAP is greater than that between Ricco's area for white-on-white stimuli and the Goldmann III stimulus. This suggests that the white-on-white Ricco's area would be expected to become larger than the Goldmann III before the chromatic Ricco's area becomes larger than the Goldmann V. Thus, for the same stage of disease, the rate of visual loss for a given rate of ganglion cell loss would be expected to be greater for white-on-white perimetry.

It has often been proposed that the magnocellular pathway is affected before the parvocellular pathway in glaucoma. The magnocellular pathway demonstrates greater sensitivity to rapidly moving (or flickering) achromatic stimuli and low spatial frequencies while the parvocellular pathway demonstrates greater colour contrast and greater sensitivity to static stimuli and high spatial frequencies. However, these two cell types display notable functional overlap (Merigan & Maunsell 1993; Pokorny & Smith 1997). Initial reports of selective damage to ganglion cells with larger axons and cell bodies (Quigley et al. 1988) were thought to demonstrate selective damage to the magnocellular pathway (Dandona et al. 1991). Thus, tests that purported to test the magnocellular pathway selectively in glaucoma (eg FDT) were devised (Johnson & Samuels 1997). Later studies do not support the notion of selective magnocellular loss (Morgan 2002). In fact, it has been proposed that what Quigley et al. (1988) probably observed during their experiments was an overall shrinkage of ganglion cells in early glaucoma, rather than a selective loss of larger neurons (Morgan 2002). While it has traditionally been thought that tests such as FDT target predominantly the magnocellular pathway and that stimuli employed in SAP target predominantly the parvocellular pathway, it should be noted that it is very likely that these tests elicit responses from both of these pathways as well as many other pathways mediated by other cell types. Recent convincing evidence points towards SAP stimuli actually eliciting a greater response from the magnocellular pathway than the parvocellular pathway (Swanson et al. 2010). Chauhan et al. (2008) recommend that, although newer tests such as FDT and SWAP

may help to confirm visual field loss in glaucoma, they should be considered as supplementary tests to SAP and should not be carried out as a substitute for it.

Frequency of testing

Although many studies deliberate the effectiveness of various tests at detecting glaucoma in the first instance as well as monitoring progression, it should also be borne in mind that frequency of testing has a sizeable influence in this regard. It is well accepted that notable variability accompanies visual field sensitivity measurements and the amount of variability can differ between patients and between normal and affected regions of the field. Confirmation of the presence of glaucoma or its progression can be hindered by high levels of measurement variability, resulting from fixation instability, learning effects, liberal response characteristics, understanding and instrument variability. Many optometrists and other eyecare professionals are familiar with the scenario where a repeated visual field test appears very different from the baseline, even when both tests are performed on the same day. Sometimes the subsequent test can reveal higher sensitivity while at other times it can reveal lower sensitivity. Often the clinician will then perform a third visual field test and consider all three in combination. The goal to interpreting visual field plots successfully over time therefore is to overcome measurement variability as best as one can at each test. Generally, for a patient who has glaucoma that is progressing, a greater frequency of testing is more likely to reveal visual field changes above variability. Currently, the National Institute for Health and Clinical Excellence (NICE) recommends performing a visual field test every 6–24 months, depending on whether the target intraocular pressure is met as well as the risk of the patient developing chronic open-angle glaucoma.

Chauhan et al. (2008) have provided useful recommendations for the frequency of testing in order to detect different rates of progression of visual field loss in patients with low, moderate and high levels of measurement variability, based on visual field data collected from patients over several years (Artes & Chauhan 2005). They report that, in order to be 80% confident of detecting rapid visual field loss (defined as –2dB mean deviation per year) among moderate variability over the space of 2 years, one must perform three visual field tests per year. However, very often patients' responses are highly variable and if progression is slow (eg when the patient is taking topical medication for glaucoma), the recommended frequency of testing increases. For example, if visual fields are measured once per year on a patient with moderate variability, it will take approximately 13 years to be 80% confident of moderate visual field progression (defined as –0.5dB mean deviation per year). If the frequency of testing is increased to twice per year, this timescale is reduced to 6.5 years and if three tests are performed in the year, the timescale is reduced further to 4.3 years. In a busy optometric practice or hospital clinic, however, it is often unrealistic to carry out a large number of visual field tests on each glaucoma patient or glaucoma suspect.

A recent study by Crabb & Garway-Heath (2009) simulated visual fields and suggested that greater confidence of the presence of progression could be achieved by using a 'wait and see' approach. Using the example of Chauhan et al. (2008) above, Crabb & Garway-Heath suggest that performing three visual field tests at the beginning of the 2-year period and three tests at the end of the 2-year period allows for better estimates of rate of loss and leads to better discrimination between progression and stability. The investigators recommend however that other tests for glaucoma progression be carried out in the meantime, with normal clinical intervention if appropriate (D P Crabb, personal communication, May 2009).

Conclusions

The assessment of visual function in glaucoma is crucial for the understanding of a patient's stage of disease as well as his or her possible visual disability. Despite reports of reduced sensitivity of standard automated perimetry to detect glaucoma presence or progression, this form of perimetry is currently that which is most widely studied and recognised by clinicians. Standard automated perimetry has imported many of the standard fixed parameters used in Goldmann kinetic perimetry and it is reasonable to suggest that a return to first principles and a redesign of currently employed stimuli (particularly varying the area of the stimulus) may afford the test increased diagnostic accuracy in a clinical setting.

Summary

This article provides an overview of recent research in perimetry as well as some emerging ideas for improving the ability of perimetric testing to detect glaucoma and its progression. It discusses the benefits of carrying out perimetric tests as part of the evaluation and management of patients with glaucoma and those suspected of having the condition, arguing that stable technology is necessary for continued monitoring. The frequency with which a visual field should be carried out in order to detect glaucoma or its progression is also discussed.

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Multiple choice questions

This paper is reference C-15697. Three points are available for optometrists. Please use the inserted answer sheet. Copies can be obtained from Optometry in Practice Administration, PO Box 6, Skelmersdale, Lancashire WN8 9FW. There is only one correct answer for each question.

1. Who is generally accredited for first describing an arcuate scotoma at approximately 15° eccentricity in glaucoma?

(a) Von Graefe
(b) Helmholz
(c) Bjerrum
(d) Goldmann

2. When were static stimuli on a bowl perimeter first utilised in perimetry?

(a) 1889
(b) 1945
(c) 1959
(d) 1972

3. Regarding visual field loss, which of the following statements is incorrect?

(a) Both the extent and depth of fields loss are important
(b) There is no evidence that glaucomatous visual field loss can increase the risk of being involved in a motor vehicle accident
(c) Visual field loss can influence hand–eye coordination
(d) Visual field loss can increase the probability of falling

4. According to Balas & Boren (2000), how long does it take, on average, for research findings to reach a clinical setting from a laboratory setting?

(a) 17 years
(b) 7 years
(c) 3 years
(d) 15 years

5. What is the duration of the stimulus generally used in SAP?

(a) 150ms
(b) 200ms
(c) 250ms
(d) 300ms

6. The background luminance used in SAP is:

(a) 1cd/m^2
(b) 5cd/m^2
(c) 10cd/m^2
(d) 20cd/m^2

7. Which of the following is not a method of altering the number of photons reaching the retina during a SAP stimulus presentation?

(a) Increasing stimulus area
(b) Decreasing stimulus contrast
(c) Decreasing stimulus duration
(d) Increasing the time between presentations

8. Which of the following describes Ricco's law?

(a) Area × Intensity = $-k$
(b) Duration/Intensity = k
(c) Area × Intensity = k
(d) Duration × Intensity = $-k$

9. At what retinal eccentricity is Ricco's area for a white-on-white stimulus approximately equal to the size of a Goldmann III stimulus?

(a) 5°
(b) 7°
(c) 15°
(d) 20°

10. According to the structure/function relationship described by Swanson et al. (2004), how much does sensitivity decline for a log unit reduction in ganglion cell density for stimuli smaller than Ricco's area?

(a) 10dB
(b) 7dB
(c) 5dB
(d) 3dB

11. Which of the following statements is true?

(a) Ricco's area is the same size at all retinal eccentricities
(b) Ricco's area enlarges in glaucoma
(c) Spatial summation describes the amount of light that passes through the cornea and lens
(d) The optical quality of the eye forms the physiological basis for Ricco's area

12. Which of the following is not true?

(a) A reduction in sensitivity of 2.5dB per log unit reduction in ganglion cell density is a consequence of incomplete summation
(b) Ricco's area differs for stimuli of different wavelength
(c) SAP is the gold-standard test for visual function in glaucoma
(d) Sensitivity measurements are more variable for larger stimuli

13. According to the structure/function relationship described by Swanson, below what sensitivity is threshold for the SAP stimulus determined by complete spatial summation?

(a) 33.4dB
(b) 30.1dB
(c) 29.8dB
(d) 31.25dB

14. To which of the following stimuli is the magnocellular pathway more sensitive than the parvocellular pathway?
(a) Coloured stimuli
(b) Flicker stimuli
(c) Stimuli containing high spatial frequencies
(d) Circular stimuli

15. According to Chauhan et al. (2008), how many years might it take to be 80% confident of moderate visual field progression with moderate variability if two visual field tests are carried out each year?

(a) 13
(b) 15
(c) 6.5
(d) 3

CPD Exercise

After reading this article can you identify areas in which your knowledge of perimetry has been enhanced?

How do you feel you can use this knowledge to offer better patient advice?

Are there any areas you still feel you need to study and how might you do this?

Which areas outlined in this article would you benefit from reading in more depth, and why?